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Alternatives in Aquacultural Development: Consideration of Extensive Versus Intensive Methods[1,2]

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For animal species having apparent potential for economical culture, the alternatives of developing extensive or intensive cultural practices are compared. Extensive culture is defined as raising fish or shellfish in natural bodies of water with few modifications of the environment, while intensive culture is defined as rearing animals in man-made ponds, raceways, or tanks where environmental control is exercised. A discussion of legal, biological, economic, environmental, and social implications of each approach is presented. It is concluded that, for most carnivorous and omnivorous species of interest to aquaculturists, expenditures for the development of extensive culture methods are not justified.

L'auteur compare les différentes méthodes à envisager pour développer, soit par des méthodes extensives, soit par des méthodes intensives, l'exploitation des espèces animales qui semblent offrir un potentiel économique. On entend par pisciculture extensive l'élevage de poissons ou de crustacés dans des masses d'eau naturelle, avec peu de modifications de l'environnement, tandis que la pisciculture intensive s'entend de l'élevage dans des lacs artificiels, des passes à poisson ou des viviers, dans lesquels le milieu est strictement aménagé. L'ouvrage analyse les incidences juridiques, biologiques, économiques et sociales de chaque formule, ainsi que ses effets sur le milieu. L'auteur conclut que, pour la plupart des espèces carnivores et omnivores qui intéressent les spécialistes, l'octroi de crédits au développement de l'aquiculture extensive n'est pas justifé.

Se estudian algunas especies animales que ofrecen posibilidades de cultivo en buenas condiciones económicas, y se comparan dos posibilidades: el cultivo extensivo y el intensivo. Por cultivo extensivo se entiende la cria de peces o mariscos en masas naturales de agua, con pocas modificaciones del medio ambiente, mientras el cultivo intensivo se define como la cría de animales en estanques artificiales, canales o tanques, donde existe un considerable control del medio ambiente. Se examinan los efectos jurídicos, biológicos, económicos, ambientales y sociales de cada uno de los dos métodos. El autor concluye que, en el caso de la mayoría de las especies carnívoras y omnívoras que interesan a los acuicultores, los gastos necesarios para aplicar los métodos de cultivo extensivo no están justificados.

Two Types of Aquaculture

EVEN though the immediate potential of aquaculture has been frequently overstated and commercially viable operations have not developed as rapidly as anticipated, interest in aquaculture remains strong. Because of this intense continuing interest, aquacultural research will probably receive considerable financial support over the next few years in both the developing and developed parts of the world.

If sizable expenditures are to be made on aquaculture, some important decisions need to be made concerning the long-term direction of this research and development. Considerable divergence of opinion exists concerning the types of animal husbandry most likely to be successful for aquatic animals. The goals of development programs range from the stocking and harvesting of animals in their natural environment to refined culture systems in which complete environmental control is exercised. The approaches to these divergent types of aquaculture are necessarily different and the probability of economic success varies for a given species depending on the approach used. Although we cannot precisely define these probabilities as present, it is imperative that we examine available information in an effort to predict the most productive developmental paths.

In this discussion extensive and intensive approaches to animal aquaculture will be compared. Extensive aquaculture is defined as raising fish or shellfish in natural bodies of water with few or no modifications of the environment; intensive aquaculture is defined as rearing animals in manmade ponds, raceways, or tanks where considerable

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environmental control is exercised. These two general approaches will be discussed with reference to problems of legal, biological, economic, environmental, and social nature. Because no clear distinction exists between these several categories, an arbitrary classification of problems has been used for discussion purposes.

Legal Aspects

While ownership of land is not a problem if no public waters are involved, it may be a serious one in extensive culture operations. In most states in the United States navigable waters and those influenced by tidal action are considered property of the state. Frequently land adjacent to these waters is also public property. While legal problems are different in each country, the difficulty in obtaining control of bodies of natural water through lease or purchase is a factor of major importance. Intensive culture can be accomplished in most cases on private land for which ownership is clear.

In navigable waters of the United States, restriction of free passage by an extensive culture operation may be illegal. Again the seriousness of the problem will vary with the particular situation, but no problem exists for intensive culture operations.

The ownership of wild animals may be a source of concern when wild juveniles are used for stocking or when wild predators or competitors are killed to protect cultured stocks. For one type of extensive aquaculture — that of stocking hatchery-reared young in their natural environment — ownership problems may be complex and may even become international in scope. Within the United States wild animals are usually considered the property of the state. Minor legal changes, if implemented, could resolve the problems of ownership of wild animals on the national level. Regulations concerning methods of harvest and minimum legal sizes are special problems that would be resolved if the farmer has clear ownership of the animals he is rearing. Until resolved, these problems are more restrictive of extensive than of intensive culture practices.

Biological Aspects

Five biological factors examined here are feeding, environmental control, disease, density, and genetics. There are many interactions between various biological factors, and a thorough examination of all factors is not possible here. The key problems to be considered in comparing extensive and intensive approaches can, however, be included in one of the five following categories.

Feeding

It has been popular to compare sea farming with agriculture and to point toward possible achievements in the sea parallel to those advancements we have seen in modern agriculture. In making this comparison two important facts are frequently overlooked. First, animal husbandry should not be confused with agronomy. Aquaculture of fish and shellfish may be compared with livestock raising, since both are animal husbandry, but the farming of plant crops involves entirely different concepts than animal aquaculture. Second, traditional animal husbandry for human consumption involves primarily herbivores, while many of the high-priced fish and shellfish considered for aquaculture are carnivores.

Two types of animal husbandry are in common practice, ranching or pasturing of herbivores and feed-lot operations. Ranching procedures extend from the practice of allowing animals to feed on natural range to the cultivation of suitable plant species in pastures. Feed-lot operations include all animal husbandry in which the nutritional requirements of the animals are provided in the feed. From an economic point of view feed costs constitute a large proportion of the expenses of rearing animals under intensive conditions. This cost is either reduced or eliminated when animals utilize natural foods. The substitution of natural foods for prepared diets represents a substantial economic advantage in favor of extensive systems.

The animals most commonly raised for human consumption are herbivores (cattle, sheep, and goats) and omnivores (hogs and poultry) which can also thrive on a vegetable diet. Many of the high-priced fish and shellfish being cultured, for example shrimps, eels, trout, plaice, and catfish, are either carnivores or omnivores. We cannot expect, based on our experience with agriculture, to raise these animals in a ranching style if they feed on other animals rather than on plants. Ranching has been successful only with herbivores. The additional complications and energy losses involved in raising animals as feed for other animals make this procedure prohibitively expensive. Generally, this approach is not being used in agriculture.

A few herbivorous species such as oysters, mussels, and milkfish are of interest to aquaculturists, and some of these species can be cultured at high densities on the natural flora present in the water. However, except for the limited culture of algae for human consumption by the Japanese, we have practically no experience in the cultivation or control of aquatic plants or algae in natural waters. Most aquatic ranching or pasturing operations will, for the present, be limited to those herbivores that can make use of plant life present in natural waters.

The implications of an animal's food requirements to its relative suitability for intensive or extensive culture are obvious. The higher the trophic level of the cultured animal the more complex a natural food scheme becomes, and the more dependent the animal becomes on supplemental feeding. Generally, more control over feed and environmental conditions is required to duplicate complex systems than to duplicate simple systems. The need for supplemental feeding is also related to the variety of food items eaten by the animal and the density of the animals being cultured. Omnivores such as catfish and shrimp can be compared with chickens; at low densities they can forage effectively on natural foods but at most commercially attractive densities supplemental feeding is necessary.

Environmental Control

In examining the major factors in an animal's environment as they pertain to intensive and extensive culture, parameters such as temperature, water quality, other animals, and plant life must be considered.

The desirability of controlling environmental factors can be reduced to a simple question of economics. The costs of modifying the environment must be weighed against additional returns from the system in terms of product produced per unit of time. At one end of the spectrum is the natural environment with no control by man, and the other extreme is complete control of all factors in enclosed tanks. Unfortunately, the research data required to select the appropriate degree of control for a given species are not available in most cases.

An alternative source of valuable information in making plans for long-term aquacultural development is the successful practices used for animal husbandry of similar domestic species. The extent to which environmental control is economically profitable with domestic animals at present should provide guidelines for predicting which types of farming will be most successful with new species. This information was used in the following paragraphs concerning environmental factors of major significance.

Temperature is a particularly important factor with poikilothermic animals since their metabolic rates change drastically with ambient temperature. At high temperatures within an animal's normal range, feeding rates, and growth are much more rapid than at lower temperatures. In some tropical areas temperature fluctuations are slight so that optimum conditions for extensive culture of certain species exist throughout the year. In areas where greater fluctuations occur, the periods of optimum temperatures are shorter, and greater value can be derived from control of temperature to permit year-round use of facilities. A good example of intensive aquaculture of a carnivorous cold-blooded animal is trout for which relatively rigid temperature control is usually exercised. Herbivores such as mussels and milkfish are, on the other hand, farmed extensively with no control of temperature.

Water quality is a critical factor in an aquatic organism's environment because of the continuous exchange of gases and other substances through the organism's gills. With extensive practices the maintenance of water quality is left to natural processes such as decomposition, photosynthesis, bacterial action, and exchange of gases with the atmosphere. The biomass of an organism supported in a body of water is limited by the rate of removal of metabolites and the exchange of oxygen by these natural processes. Supplemental water treatment practices are used to speed these processes or remove wastes to an increasing extent with more intensive culture systems. Control of water quality in intensive systems is accomplished by exchanging water, circulating or aerating the water, and removing particulate matter or debris physically. Other possible means of control are those commonly used in the treatment of industrial or domestic wastewater including sedimentation, physical and chemical filtration, air stripping, biological filtration, and chemical treatment. Each process for removal of undesirable wastes involves additional costs. In most cases sufficient data are not available to predict the economic benefits of water quality control on a commercial scale.

Farmers have generally been unsuccessful in attempts to rear livestock in the presence of their natural predators and competitors. Even in ranching operations predators are usually eliminated. Based on this experience aquaculturists will probably have to control predators to some extent in any type of system. Potential predators include insects, crustaceans, fish, reptiles, and mammals (including man), and the control of such a variety of animals over large areas of water required for extensive operations is practically impossible. In intensive systems involving smaller areas and less water volume, control of predators and competitors is possible. Experimental shrimp culture in seminatural bodies of water in the United States has been characterized by great variation in survival rates. The instances of poor survival are probably due to predation although no thorough studies of the causes of these mortalities have been made. It is likely that the farmer's inability to control predators in large natural bodies of water will be a major hindrance to development of profitable extensive practices.

The control of competing species is important because their presence can cause considerable loss of efficiency through undesirable competition for food, oxygen, and space. In natural or seminatural culture systems the control of undesirable species poses a major problem. An advantage of intensive systems is their suitability for the control of competing species.

Although some plant growth in a culture system is normally beneficial, excessive growth may interfere with harvesting, or may be harmful when large quantities (either vascular or algal plants) decompose and create oxygen deficiencies. Plant growth is often excessive when nutrient levels have been increased by feeding or fertilizing. Control can be accomplished in small, intensive systems, but most methods, including chemical applications, are not practical in large systems.

Disease

Disease problems are encountered less frequently in extensive culture systems than in intensive systems. Crowding and feeding prepared diets contribute to disease problems.

Treatment for disease is usually accomplished by one of the following three methods: removal of animals from the water for treatment, changing the water quality to kill parasites, or chemical treatment through feed additives. None of these can be done economically in an extensive system. Similarly, prophylactic measures can be taken in intensive systems but are not feasible for extensive culture.

Density

An important biological factor frequently ignored in planning a culture operation is the behavior of the animal under crowded conditions. Territorial or aggressive behavior may make a species undesirable for use in intensive systems. Freshwater shrimp and many crabs are examples of animals that exhibit behavior which makes them unsuitable for high density culture.

Yields of species from any system vary over a wide range depending on the densities that can be supported. Densities range from an upper limit determined by the behavior of the animal downward in relation to the degree of environmental control exercised and the amount of food supplied. With most domestic animals, we have bred varieties better suited to life in crowded conditions, i.e. we have changed the animal's behavior through selection. Aquatic animals can undoubtedly be bred selectively, as well, to increase their tolerance to crowding so that species presently being considered only for extensive culture may be used in intensive systems.

Genetics

Successful animal husbandry today is dependent on improved breeds of animals; varieties which have been selectively bred for survival and growth in captivity. With a few aquatic species such as carp and trout selective breeding for strains suited for intensive culture has been accomplished. However, the stocks of most species being used experimentally for aquaculture are wild rather than domestic varieties. While wild strains can be expected to do well under seminatural conditions, the potential for growth and survival in intensive systems cannot be evaluated adequately with wild varieties. The potential benefits to be derived from domestication of wild species are clear when we compare wild and domestic varieties of geese, ducks, or hogs. The ability of most wild aquatic species to utilize an intensive culture environment and compounded foods can probably be improved significantly through selective breeding.

Economic Aspects

Nearly all considerations in the evaluation of a commercial operation are ultimately expressed in economic terms. However, for purposes of this discussion some aspects of only four topics — facility costs, competing uses of environment, operational costs, and dependability — will be examined. Applicable data for most individual situations are lacking so research must be planned from general information at hand.

Facility Costs

The direct costs of a facility are generally much less for extensive culture than for intensive culture even though the area required is much less for an intensive system. The purchase of necessary equipment for even minor environmental control requires substantial capital. The cost of an extensive facility may, on the other hand, be low if natural waters can be obtained free or leased at a low rate. Many countries are willing to lease public waters for a small rental fee to encourage the development of new industry.

An exception exists when estuarine areas and adjacent land have a high value for other uses such as housing developments. In these cases coastal land may be a major cost, and it may be desirable to utilize less expensive land further from the water. The culturist is then forced to use some form of intensive culture.

Competing Uses of Natural Waters

Even though a private company may be able to obtain possession of natural waters for extensive culture at low cost, this cost probably does not represent the actual economic loss to society incurred by the commitment of the waters to aquaculture. Actual economic losses would be imposed upon the following groups:

The commercial fishing industry, through loss of productive areas and possibly through the loss of larval animals produced elsewhere.

The recreational fishing and boating industry, if the area can no longer be used for recreational purposes.

Industries, municipalities, and private home owners, if the area had been used for waste disposal and can no longer be used for that purpose.

Industry, if culture activities interfere with water transportation.

In planning approaches to aquaculture the long-term projected uses of all resources involved must be examined carefully. The potential economic value of many coastal areas for housing and recreational uses in particular frequently overshadows the potential contribution from aquaculture. Multiple-use of many estuarine areas will certainly be necessary in heavily populated areas. For efficient use of research funds probable uses must be anticipated by administrators, and aquacultural research must be directed accordingly.

On the positive side, modifications of natural areas for extensive culture are neither expensive nor permanent. Since few if any irreversible changes are made for extensive culture, experimentation with extensive culture can be conducted for short periods in many situations without competition to other uses of the natural waters.

Private land for intensive culture is normally sold to the user willing to pay the highest price. For this reason problems of multiple-use and competition between various users do not arise as they do on public property.

Operational Costs

Because present knowledge of operational expenses is scanty, direct comparisons between operational costs of extensive and intensive culture practices cannot be made. The following list of activities will serve as a point of reference for comparing various types of culture operations:

Stocking — No major differences exist in stocking procedures.

Feeding — Costs of distributing feed are roughly proportional to the area under culture. Feed distribution costs per animal decrease as animal density increases. Feeding is not necessary in some extensive operations.

Environmental control — Mechanical aeration and temperature control cannot be used on an extensive basis for economic reasons, but can be used in intensive systems.

Water exchange and circulation may be accomplished by tidal action, water currents, or mechanical methods (costs of mechanical methods are related to area under cultivation).

Only limited predator or competitor control are possible in extensive operations, but complete control is possible in intensive operations.

Disease treatment and control — These are not possible in extensive systems.

Security — Costs of patrolling are directly related to size of the area.

Harvesting — Harvesting is considerably more expensive in natural waters than in man-made tanks or ponds.

Reliability

The reliability of an aquaculture operation to produce expected results is extremely important from an economic point of view. Generally, the less subject the operation is to losses from natural phenomenon such as storms, drought, extreme temperature and floods, the more reliable the operation becomes. The environmental control required to free the operation from these risks is expensive.

Experimental aquaculture has been characterized by frequent failures. Through research the biological problems can be solved. Weather related problems, however, will persist regardless of man's skill as an aquaculturist. By definition extensive culture systems are more vulnerable to problems created by unfavorable weather.

Environmental Aspects

An aquaculture facility may either be affected by environmental modifications made for other purposes or it may cause environmental changes. Some of these changes should be considered in planning for aquaculture.

Housing developments adjacent to culture facilities may have a direct effect. Pollution of water supplies may be a a result of direct dumping into culture areas from domestic, industrial or agricultural sources. Spraying for purposes of insect control is another source of pollutants which must be considered. Diversion of natural fresh water supplies for power, irrigation, or other uses is a likelihood in many areas. These factors could each have pronounced effects on extensive culture operations as well as changing the quality of water sources used for intensive operations.

Other environmental modifications such as the construction of channels for shipping or the construction of storm protection levees can have similar adverse effects.

Intensive culture facilities are likely to cause pollution of the environment in the sense that their effluents are different than the natural water introduced into the systems. Experimentation is beginning with closed intensive systems that produce no effluent. Little if any pollution is likely from extensive systems unless animals are fed heavily or chemical control of predators is practiced.

The introduction of foreign species either purposely or inadvertently may cause ecological changes. Both the risk of introducing diseases to native animals and the risk of introducing exotic species are greater in extensive operations than in intensive culture systems. This is not a problem, however, if only native species are cultured.

Social Aspects

Social and political considerations cannot be ignored because they dictate the availability and distribution of money for research. In areas of high unemployment, practices requiring a large labor force may be encouraged as opposed to an automated operation. While the introduction of automated aquaculture into an area where none existed would provide employment, the replacement of traditional practices with automated procedures might reduce employment.

As man becomes more aware of the quality of his environment, aesthetic changes caused by aquaculture may be reasons for resistance to further development. Pollution in the form of odors or changes in water color may be objectionable. One example is the objection by home owners along the west coast of the United States to the placement of oyster culture rafts suspended in public waters near their homes. Another example is the legislation resulting from a sudden affection for marine mammals by the United States public. Sea otters are protected regardless of their damage to a valuable fishery product, abalone.

The many possible social factors affecting aquaculture are too numerous to discuss here. These problems are compounded when ownership of the culture area is uncertain or when public waters are used for culture.

Conclusions

Although the culture of each species in each location will require separate decisions concerning the appropriate degree of environmental control, general conclusions can be made based on information available at this time.

Legal problems involving extensive culture on public land will probably present major obstacles to this approach. While some improvement of this situation may occur, the development of intensive culture on privately owned land has clear advantages over extensive culture on public land.

Biologically the relative effectiveness of intensive and extensive approaches varies considerably, depending upon the species, its feeding habits, behavior, and environmental requirements. Our experience with other forms of animal husbandry suggests that with most species intensive approaches are more efficient than extensive approaches. Major differences noted between mammals or poultry raised in traditional animal husbandry and the fish and shellfish being considered for aquaculture with respect to food habits and the animals' ability to control body temperature are arguments in favor of intensive culture. Animals that may be raised successfully on an extensive basis are those herbivorous filter feeders which can utilize a wide variety of plant species as food.

Initial costs of a facility are higher with intensive culture while indirect costs to other users of the culture area are higher with extensive culture. Sufficient data are not available to make general comparisons of operational costs or of yield from a given investment.

An extensive culture system is highly subject to losses due to environmental changes. Regulation of effluents from a culture system may hamper either extensive or intensive operations unless the systems are closed with no effluent.

Social considerations are extremely complex and must be dealt with separately in individual situations. Indirect costs to other users of natural areas must not be ignored. Since the private aquaculturist does not always have to bear all these costs, his decision to conduct an extensive culture operation for personal gain may not be compatible with the resource manager's decision which must take into consideration all uses of natural waters. Even the resource manager may be biased by the opportunity for a short-term measurable product from the natural areas as opposed to the less tangible values of the area to present users.

The author's opinion is that, with a few exceptions, extensive aquaculture is not likely to be economically feasible. Furthermore, when all direct and indirect costs of extensive aquaculture are considered, the direction of research efforts toward the development of techniques for extensive culture does not appear to be warranted. On the basis of available knowledge and comparisons with modern animal husbandry the rearing of most omnivorous and carnivorous species will probably require the use of intensive culture techniques for economic gain.